Microstructural Evolution and Hardness Profile of High Nitrogen Austenitic Steel After Arc-laser Hybrid Welding

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Abstract. An arc-laser hybrid welding was performed on high nitrogen austenitic steel which was used in the industries. Micro-vickers hardness tester, Optical microscopy, secondary and backscattered electron beam image analysis, image analyzer and Energy Dispersive X-ray Spectroscopy (EDS) in Scanning Electron Microscopy (SEM) were applied to reveal the microstructural details. The results indicate that, the microstructures of the weld bead are consisted of the dendrite-like austenitic phase and the small rod-like delta ferritic phase located between the dendrites. The solidification mode of the bead is AF mode. The grain size in heat affected zone (HAZ) is larger than the parent metal, and the near the bead area, the larger the size of the grain.

Introduction

The mechanical properties of high nitrogen austenitic stainless steel strongly depend on the weight percent of the nitrogen as an interstitial solution element [1]. Moreover, the solution treated high nitrogen steel shows more thermal sensitivity in the heat processing such as hot rolling and welding process with the increasing heat input [2]. Many investigations [3-6] have been carried out in the mechanical properties of high nitrogen austenitic stainless steel, which represents a combination of strength and corrosion resistance without much loss of toughness through relatively low production cost. Besides, usually it is difficult to find the published data for the effect of the arc-laser hybrid welding that has a low heat input characteristic on the solidification mode of the weld bead and ageing precipitation for the high nitrogen austenitic stainless steel. Therefore, it is urgently necessary to systematically investigate the solidification behavior of the weld bead and the effects of its heat input on the ageing precipitations, in order to widen the use of the high nitrogen steel to the industries.

Experimental Procedure

The section headings are in boldface capital and lowercase letters. Second level headings are typed as part of the succeeding paragraph (like the subsection heading of this paragraph).

The size of the high nitrogen austenitic stainless steel plate used in this test is 400x300x8mm. A V-shape groove was machined on the upper face as shown in Fig. 1. The angle of the groove, thickness of root face, and gap of two plates are 60°, 2.5mm, 0.6mm, respectively.
Figure 1. Schematic sketch and sizes of the V groove butt welding.

The chemical compositions of high nitrogen austenitic steel plates used to the butt welding are 0.03C-0.21Si-20.43Mn-20.37Cr-1.74Ni-0.64N (wt.%). The high nitrogen austenitic steel plates were manufactured by the Capital Steel Company Ltd. in China. The manufacturing process of the plates was sequentially continuous-cast, several passes hot-rolled, and finally on line-quenched in order to get higher strength.

Diameter of filler wire is Φ1.2mm, and its chemical compositions used to weld the high nitrogen steel plates are 0.02C-0.30Si-16.20Mn-19.70Cr-2.12Ni (wt.%). The manufacturing process of the filler wire was cast, hot-rolled to wire, followed by cold-drawing in order to increase its strength and stiffness. Table 1 shows the arc-laser hybrid welding parameters. The laser power was changed five steps of 1.2KW, 1.9KW, 2.6KW, 3.3KW and 4.0KW in order to evaluate the hardness profile of the weld joint.

Table 1. Arc-laser hybrid welding parameters.

<table>
<thead>
<tr>
<th>Welding current/A</th>
<th>Laser Power (KW)</th>
<th>Laser Focal point under the surface of the plates (mm)</th>
<th>Welding speed (mm·m in⁻¹)</th>
<th>Distance between arc and laser beam (mm)</th>
<th>Shield gas Type</th>
<th>Flow rate (liter·min⁻¹)</th>
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<tbody>
<tr>
<td>220/26</td>
<td>1.2, 1.9, 2.6, 3.3, 4.0</td>
<td>-2.0</td>
<td>13.0</td>
<td>3.0</td>
<td>95%Ar+5%CO₂</td>
<td>16</td>
</tr>
</tbody>
</table>

Test Results and Discuss

Figure 2. Original optical microstructure of the high nitrogen stainless steel.

Fig. 2 shows the original optical microstructure of the high nitrogen austenitic steel. It is revealed that, the microstructure of the high nitrogen austenitic steel is totally composed of the equiaxed grains with the average size of 7.9μm. There are a few rolling lines formed during hot rolling process.
Figure 3. Microstructures of the welded joint for the high nitrogen austenitic steel.

Fig. 3 shows the microstructures of the welded joint for the high nitrogen austenitic steel, (a) for the bead, (b) for the enlargement of the (a), and (c) for the HAZ, all etched by the etchant of 38% HCl:68%HNO₃:H₂O=2:1:1. It clearly shows that, the microstructures of the weld bead are consisted of the dendrite-like white phase and the small black rod-like phase located between the dendrites. In order to observe it more clearly, it is being enlarged (SEM photograph shown in Fig. 3(b)), and found that, there is nothing within the small black rod-like area in the Fig. 3(a), and just shows the rod-like grooves. It can be predicted that, the locations of the grooves used to be one kind of rod-like phase, which was being removed as it has lower etching resistance than the matrix areas.

Figure 4. X-ray diffraction pattern within the bead.

It is difficult to evaluate the microstructures within the bead by just microstructural observation and analysis, so an X-ray diffraction test was carried out within the bead (Fig. 4). It is revealed that, almost all peaks are related to the austenitic microstructure, and just $F(110)$ small peak
indicates the small percentage of ferritic phase existed in the bead, meaning the solidification mode for the weld bead is AF mode. Moreover, there is nothing microstructural change within the HAZ, and just shows that, the average austenitic grain size within the HAZ is bigger than the parent metal (shown in Fig. 3(c)). The near the fusion line, the bigger the grain sizes. The average grain size within the HAZ is gradually changed from 44.9μm, 22.5μm, and 11.2μm.

(a) SEM back-scattered image (b) EDS line scanning and the fluctuations of the Cr and Mn (c) respectively

Figure 5. Microstructures of the bead for the SEM second electron image.

Fig. 5 shows the microstructures of the bead for the SEM second electron image (a), SEM back-scattered image (b), EDS line scanning and the fluctuations of the Cr and Ni (c), respectively. The etchant that used in the etching sample here, is different from the etchant of 38%HCl: 68%HNO₃: H₂O=2:1:1 applied in Fig. 3. It is made of by the ratio of 38% HCl: 68%HNO₃ =3: 1 and lay aside for three days ahead of etching. It is clearly observed that, rod-like phases show the color of dark gray, and have distinguishable boundaries with the matrix (Fig. 5(a) and (b)). An EDS line scanning was carried out to the region which has rod-like phase (Fig. 5(b)). When the scanning line meets the dark rod-like phase, the line scanning content of Cr reveals the peaks. At the same position, that of Mn contrarily appears the troughs, meaning there are more Cr content and less Mn content within the dark-gray rods.

Table 2. EDS quantitative point analysis for the weld bead (wt.%)*.

<table>
<thead>
<tr>
<th></th>
<th>Cr</th>
<th>Mn</th>
<th>Ni</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matrix</td>
<td>21.28</td>
<td>18.27</td>
<td>1.59</td>
<td>Balance</td>
</tr>
<tr>
<td>Rod</td>
<td>24.28</td>
<td>13.84</td>
<td>0.94</td>
<td>Balance</td>
</tr>
</tbody>
</table>

* The data shown is averaged from five point measurements.

In order to more exactly evaluate the chemical compositional changes within the dark rod-like phase, the quantitative point EDS analysis was carried out in the sample (Table 2). The average contents of Cr, Mn and Ni in the matrix are 21.28%wt, 18.27%wt and 1.59%wt, respectively. But within dark rod-like phase, the ferrite forming element Cr content is 14.1% higher than the matrix nearby, in contrast, the austenite forming element Mn and Ni are 24.2% and 40.9% lower than the matrix. From the viewpoint of the feature of the chemical compositions, shape, and the solidification mode of the bead, it can be definitely concluded that, the dark rod-like phase is delta ferritic phase, and the matrix is austenitic phase. It is completely identical to the analysis of the phases which existed in the weld bead (shown in Fig. 4). The solidification process just can be analyzed like this that, when arc-laser hybrid welding
is being carried out, the austenitic phase solidification starts at the fusion line along the direction which is favorable to grow into the dendrites. As the austenite growth needs to consume more elements of Mn and Ni, and discharge Cr when dendrites grow to near the end, the austenitic forming elements Mn and Ni are less and less, and the ferritic forming element Cr is more and more contrarily. Finally, the rod-like ferritic phase will be transforming from the remaining liquid which located between the solidified austenitic dendrites. In addition, as the boundaries which form the ferritic phase have a lot of inclusions segregated, and the etching resistance of ferrite is lower than the austenitic microstructure, the rod-like ferritic phase is more easily etched out. So it is difficult to observe the ferritic phase when it was etched by the normal etchant (shown in Fig. 3(b)).

![Figure 6](image)

Figure 6. Hardness profile of the weld joint after a series of increasing the laser power from the 1.2KW to 4.0KW.

As shown in the Fig. 6, the hardnesses of the bead are basically remained at HV240-270, whereas, the hardnesses of the HAZ increase sharply. That is to say, the near the fusion line is, the harder the hardnesses are. So the hardnesses of the HAZ increase from the HV240-270 at the fusion line to the HV370-390 at the boundary between the HAZ and parent metal (original part). The widths of the HAZ are also increased when laser power increases from the 1.2KW to the 4.0KW. the mechanism of the hardness profile appeared to be trough like, is that, high nitrogen austenitic steel is made through the hot rolling and on-line quenching process, so a number of the crystalline defects created in the parent metal such as vacancies, dislocations, stacking faults etc. these defects must increase the harness of the parent metal by the mechanism of the solution and dislocation strengthening. But when joint gets through the laser-arc hybrid welding process, the vacancies and dislocations will be decreased sharply by the recovery and recrystallization process. That is the cause of why the hardness profile of joint is trough like.
Summary

The main purpose of this work is to pave the way for applying the arc-laser hybrid welding to the high nitrogen steel that used in the industrial applications. From the systematic analysis above, we can get conclusions as follows.

1) The microstructures of the weld bead are mainly consisted of the dendrite-like austenitic phase and the small black rod-like delta ferritic phase located between the dendrites. Therefore, its solidification type is the AF mode.

2) The near the fusion line, the bigger the grain sizes of HAZ. The average grain sizes within the HAZ are gradually changed from 44.9µm, 22.5µm, and 11.2µm, respectively.

3) The hardnesses of the bead are basically remained at HV240-270, whereas, the hardnesses of the HAZ change from the HV240-270 at the fusion line to the HV370-390 at the boundary between the HAZ and parent metal (original part).

Acknowledgement

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References